

Table 1 Thermal Coefficient of Expansion* of Metals

Temp, F	Aluminum	Copper	Steel	Zinc
70	12.8×10^{-6}			
-148	10.1			
-328	6.4			
77-570		9.3×10^{-6}		
-300-0		6.85		
-420 to -315		2.16		
32 to 212			6.7×10^{-6}	
-310 to 68			5.1	
70				22×10^{-6}
-250				10.2

$$\alpha = \left(\frac{1}{L} \right) \left(\frac{dL}{dT} \right) \left(\frac{1}{F} \right)$$

behavior of the material under a controlled set of conditions. The matter of cost is a paramount one and involves not only the unit price of the material, but the cost of fabrication. The type of fabrication required may be a controlling factor, and of equal importance may be availability of the material in the sizes and forms required. If special skills are required for fabrication, facilities may not be readily available. Each of these factors should be weighed before making the final selection.

Quenched and tempered low alloy steels of the AISI or SAE types frequently are used in light and moderate sections of machinery parts that are to operate at temperatures down to -150 F. A type of steel should be selected that will fully harden on quenching, and if any welding is performed, it should be done prior to the quenching treatment. Low carbon quenched and tempered steel plate is finding increased use in the fabrication of pressure vessels, but, in this case, welding is performed on the heat treated steel plate and further heat treatment, except for stress relief anneal, is not applied. The limiting low temperature for such vessels is usually dependent upon the properties of the weld metal.

For structural components, aluminum treated low carbon steel frequently is used in light sections for temperatures down to -50 F; low carbon nickel steel containing up to about 3½ percent nickel are generally selected for temperatures down to -150 F, and copper and copper alloys, nickel and Monel, chromium-nickel stainless steels, aluminum alloys and low carbon high nickel steels all have been used for temperatures below -150 F.

The choice of materials for large pressure vessels and towers has probably received more attention than any other phase of the low temperature problem. Because of almost universal use of welded construction for these parts, it is essential that a material be used that can be welded by an accepted commercial process, and that welds have resistance to low temperature embrittlement approaching that of the base material. In addition, the properties of the base material must not suffer deterioration from the heat of welding, or at least to an extent that cannot be corrected by a simple form of heat treatment such as a stress relief anneal. This immediately eliminates steels that derive their resistance to low temperature embrittlement from full heat treatment. As rolled or normalized, aluminum treated low carbon steel, welded with AWSE 6015 electrodes, is used for comparatively thin wall vessels for temperatures down to -50 F. Low carbon, 2½ percent nickel steel welded with AWSE 8105 nickel steel electrode generally is used for temperatures down to -75 F or slightly lower, and low carbon, 3½ percent, nickel steel,

welded with AWSE 8015 nickel steel electrodes, has been employed for temperatures down to -150 F.

For temperatures below -150 F, the engineer has a choice of a number of materials. Copper and copper-base alloys meet the low temperature requirements, but special skill is required for making welds in heavy plate. Nickel and Monel are satisfactory from almost every consideration except cost. Chromium-nickel stainless steel has probably been used more extensively than any other material, but here again, cost is an objectionable feature. The principal problem associated with its use is selection of electrodes that will develop suitable low temperature properties in the weld, and at this time types 304 and 310 electrodes appear to best meet the requirements.

Aluminum alloys have been receiving increasing attention and offer certain advantages, among which is their moderate cost. The aluminum alloys that have best welding qualities are limited to those of tensile strength of less than 40,000 psi. There are also certain problems associated with the welding of thick sections of aluminum alloys that have not been completely solved as yet.

The recently developed low carbon high nickel steels offer considerable promise for use at temperatures below -150 F. They retain a considerable degree of toughness at temperatures down below that of liquid nitrogen, they possess high strength and ductility and may be welded satisfactorily by any of the commercial welding processes. Electrodes for arc welding have been limited to type 310 stainless and 80 percent nickel-chromium alloy, as welds made with ferritic steel electrodes have not had the required impact properties at very low temperatures. The unit cost of this material is somewhat lower than the cost of any of the nonferrous metals, and fabricating costs compare favorably with those for low carbon steels.

Cast iron is usually considered a brittle material at normal atmospheric temperatures, but there are many applications where it is used successfully, even when some degree of shock resistance is required. Impact measurements on cast iron usually are made on unnotched arbitration test bars 1.2 in. in diameter, and although the resistance to impact decreases as the temperature is lowered, a sharp transition temperature has not been observed. The plain cast irons have very low resistance to impact, both at room and low temperatures, but some of the alloyed cast irons possess a moderate degree of toughness. The high alloy irons of the Ni-Resist type have appreciably higher toughness, but both the low alloyed and Ni-Resist types show a drop of 25 to 30 percent in impact values from room temperature down to -300 F. Since the im-

Table 2 Thermal Conductivity* of Metals

Temp, F	Aluminum	Copper	Steel	Zinc
932	155	207	22	
752				54
212	129	218	28	57
32	122	224	28	63
-250	124	266	25.8	68
-390	1,000 + (peak)			
-460	460	1,000 + (peak)		

* k = Btu per (hr) (sq ft) (F deg per ft).

past resistance of low alloyed high strength cast irons is of the order of 25 to 30 ft lb at room temperature, and that of Ni-Resist 80 or more ft lb, the impact values at -300 F are about 20 ft lb for grey iron and 50 to 90 ft lb for Ni-Resist. These values cannot be compared with impact properties of steels and metals that are measured with notched specimens about 0.4 in. square, as such specimens are unsuitable for measuring differences in metals that are inherently brittle.

Thermal Shock and Thermal Fatigue

Rapid changes in temperature in a system may set up stresses that exceed the yield point in localized areas of the surrounding metal. When the yield point is exceeded, plastic flow occurs, and if the conditions are recurring such as in cyclic operation, fracture may ultimately take place. Such failures are usually referred to as thermal fatigue. Under the most severe conditions fracture may occur in one or in only a few cycles. This rapid change in temperature which imposes peak stresses that exceed the yield point in localized areas is generally referred to as thermal shock. The properties most conducive to resistance of thermal shock are high thermal conductivity, low coefficient of thermal expansion, low modulus of elasticity, high yield point and high ductility. No metal has all of these properties, but some have a more desirable combination than others for resisting thermal shock. For instance, copper is considered much better for this purpose than steel.

SPECIFICATIONS

Standard specifications covering ferritic steels for low temperature service have been issued by the American Society for Testing Materials and are recognized in the ASME Code for Unfired Pressure Vessels. Plate steels for low temperature service are covered by ASTM Specification A300, steel bolting is covered by Specification A320, and seamless and welded steel pipe by Specification A333. Seamless and welded steel tubing is covered by Specification A334, forged flanges and fittings by A350, and steel castings by A352.

The chromium-nickel stainless steels are being used with

increasing frequency for temperatures approaching that of liquid nitrogen and below, as these steels can be readily fabricated and are not embrittled at temperatures as low as have been measured. An added advantage is that vessels of nickel-chromium stainless steel can be field-welded, as subsequent heat treatment is not necessary, unless certain corrosive conditions are encountered.

PHYSICAL CONSTANTS

Although the effect of low temperatures on the mechanical properties of metals and alloys has been widely studied during the past decade, information on the effect of low temperature on the physical constants is rather scattered and not always in agreement. Data on thermal coefficient of expansion, thermal conductivity, and electrical resistivity have been assembled for aluminum, copper, steel, and zinc and are given in Tables 1, 2, and 3. These values were taken from the published literature including such sources as the National Bureau of Standards, American Society for Metals Handbook and private communication from Dr. S. C. Collins at the Massachusetts Institute of Technology.

REFERENCES

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- ² L. Seigel and R. M. Brick: Mechanical properties of metals at low temperatures, a survey (*American Society for Metals Transactions*, Vol. 40, 1948).

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Table 3 Electrical Resistivity of Metals

Temp, F	Ohms, cm			
	Aluminum	Copper	Iron	Zinc
212	3.86×10^{-4}	2.28	14.5	8.0 (197)
32	2.63	1.63	9.7	5.75
-150	1.53	0.904	5.9	3.34 (-108)
-308	0.64	0.163 (-340)	0.84	1.62